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# Operating and Service Manual for the NASA Lewis Automated Far-Field Antenna Range

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# **OPERATING AND SERVICE MANUAL FOR THE NASA LEWIS AUTOMATED FAR-FIELD ANTENNA RANGE**

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## **SUMMARY**

This manual describes the operating procedures for the NASA Lewis automated far-field antenna range and the theory of operation for the controller system. It is intended for persons who know radiofrequency and microwave measurement techniques and electronic hardware design.

## **1.0 OPERATING PROCEDURES**

This section describes the procedures for configuring the test hardware and for operating the Far-Field Antenna Measurement Program (FAMP). Included are the steps for getting started and for installing the proper microwave equipment.

### **1.1 Hardware Configuration**

In setting up for a test all the constituent components must be turned on and allowed to warm up for at least 1 hour. These components are shown in figures 1 to 3 and listed here:

- (1) Hewlett Packard (HP) personal computer—the system controller
- (2) HP 8709A synchronizer
- (3) HP 59313A analog-to-digital converter
- (4) HP 8410 microwave receiver
- (5) Scientific Atlanta (SA) digital synchronizer display
- (6) Pedestal axis select unit
- (7) Antenna measurement and control unit
- (8) HP programmable power supply
- (9) Limit switch power supply
- (10) Fluke programmable digital multimeter
- (11) HP microwave amplifiers (2)
- (12) HP 8350A signal source
- (13) HP 8340B local oscillator
- (14) Microwave three-band select unit
- (15) Motor control interface

While the equipment is warming up, the system can be configured for one of three frequency bands (2 to 18, 18 to 26.5, or 26.5 to 40 GHz) as follows:

- (1) Install the proper horn for the desired frequency band. Information on the horn frequency range and gain can be found in the book labeled "Far-Field Antenna Facility Information" located in the cabinet in the far-field range.

(2) Connect the radiofrequency (RF) output of the local oscillator to the RF amplifier input on the back of the three-band select unit.

(3) Connect the power splitter output on the front of the three-band select unit to the input of one of the HP microwave amplifiers.

(4) Connect one end of the semirigid coaxial cable to the output of the microwave amplifier; connect the other end to the local oscillator input of the mixer that is located at the pedestal. However, please note that it may be necessary to connect an Avantek miniature microwave amplifier between the semirigid coaxial cable and the local oscillator input of the mixer when testing in the 26.5- to 40-GHz range.

(5) Connect one of the three semirigid coaxial jumpers that are located on the side of the three-band select unit to the mixer input connector and to the -20-dB output connector corresponding to the desired frequency band.

(6) Connect the flexible coaxial cable to the "x" output of the mixer that is located at the pedestal.

(7) Connect the RF output of the signal source to the RF input connector corresponding to the desired frequency band of the three-band select unit. To configure for the 26.5- to 40-GHz band, perform the following: Connect the RF output of the signal source to the remaining HP microwave amplifier; connect the amplifier output to the source module input; connect the source module cable to the input on the front of the amplifier (see fig. 2); and connect the source module output to the waveguide connector on the back of the three-band select unit.

(8) Connect the flexible coaxial cable to the mixer output connector on the front of the three-band select unit. Last, connect the horn input to the RF output connector that corresponds to the desired frequency band on the front of the three-band select unit. At this point the system configuration is complete. The system can now be programmed to run the desired tests.

## **1.2 Far-Field Antenna Measurement Program**

FAMP is used to program the system for the desired tests. FAMP is automatically loaded during computer powerup, or it can be started by typing "famp" at the disk operating system (DOS) prompt. FAMP has five major menu options: create setup file, edit file, run test, view data, and quit. Each option is discussed in detail here.

**1.2.1 Create setup file.**—The first option is called create setup file. This option can be chosen by aligning the mouse cursor with a letter in the words "create setup file" or by pressing the "c" key on the keyboard. Note the following:

(1) The program is not case sensitive.

(2) Any other menu or menu option in the program can be selected by aligning the mouse cursor with the title of the menu or menu option desired.

(3) Any menu or menu option can be selected by pressing the key that corresponds to the highlighted letter in its title.

Once the menu has been chosen, a popout menu appears on the screen. There are three selections: frequency sweep, pattern, and return to main menu.

*1.2.1.1 Frequency sweep mode:* The first selection in the create setup file popout menu is the frequency sweep mode option. This option creates the setup or control file needed to run a frequency sweep test. This option can be selected by using the mouse cursor or by pressing the "f" key on the keyboard. This file contains seven field entries that completely define the test run:

(1) The first field is the antenna identification. This field is where any identifying nomenclature of the test antenna should be typed in. It holds up to 20 characters. Also, for this field and all other fields in the program, you must press the return key to store the characters displayed on the screen. Therefore the inputs can be edited by using the insert, delete, and backspace keys if the return key has not already been pressed. This field is printed on the bottom of the graph of the test data.

(2) The second field is the test date. The default for this field is the computer system's date. This can be changed by typing the new date and pressing "return." Note that the arrow keys are not active in this program; consequently one cannot move the cursor over a character without erasing it from the screen. Therefore each character in the new date or any other field must be retyped. This field is also printed on the graph of the data next to the antenna identification.

(3) The third field is the start frequency. This field accepts numeric inputs and assumes that all values are in units of gigahertz. Of course, this field accepts only positive numbers. If a negative number is typed in, the computer beeps and displays a message saying "invalid input ...please wait." You will then be allowed to input a new value.

(4) The fourth field is the stop frequency. Again this field accepts only numeric inputs and assumes that all values are in gigahertz. The entry in this field must be greater than the entry in field 3; otherwise an error occurs.

(5) The fifth field is the step frequency. The inputs to this field are numeric. In addition, the value placed in this field must be less than the difference between the stop and start frequencies. If either condition is not met, an error occurs. This error is handled by the error-trapping routine, which allows you to correct the error.

(6) The sixth field is the power level. This field sets the power levels of the signal generator. The input to this field is also numeric, and the unit of measurement is decibels referenced to 1 milliwatt. Note that the input to this field cannot exceed 10 dBm without generating an error. This protects the receiver from possible damage.

(7) The last field is the position of the test antenna. This position remains constant throughout the frequency sweep. The input to this field is numeric, and the range of valid inputs is  $-90^\circ$  to  $90^\circ$ , inclusive. Usually this position is set to boresight,  $0^\circ$  for this system; however, if some angle other than zero is of interest, this angle can be entered as long as the value is within the stated limits.

After the input to the last field has been stored, you are asked if you would like to change one of the fields. If you choose to change one or more field, type "y" and hit "return." Next

you are asked to type in the number corresponding to the field to be changed. The only valid inputs are the numbers 1 to 7. Pressing any other key generates an error and causes the computer to beep.

Once a field has been chosen, the cursor moves directly under the first character in the previous answer. You need only type in the new response and hit "return" to save the new value. Now you are asked if you want to change any more values. If so, press "y" and repeat the preceding steps; otherwise press any other key. Next you are asked if you wish to save the responses to a file. Press "y" to start this process; press any other key to exit to the main menu. If you press "y," you are prompted to specify a drive. This option allows the file to be saved on a floppy diskette as well as on the hard drive. If you hit "return" without specifying a drive, the file is still saved on the hard drive. Next you are prompted to type in a file name (eight characters or less). If the file name has more than eight characters, an error is generated and the computer beeps. After a brief delay you are allowed to type in a new file name. When the file has been saved, the program exits to the main menu.

**1.2.1.2 Pattern sweep mode:** The second selection in the create setup file menu is the pattern sweep mode option. This option creates a setup or control file to run a pattern sweep. This option can be selected by using the mouse cursor or by pressing "p" on the keyboard. Once the pattern sweep mode has been selected, the program exits to the pattern sweep screen of the setup menu. This menu option is very similar to the frequency sweep option; consequently the same degree of detail is not repeated in the paragraphs to follow. Refer to the frequency sweep mode instructions for more details.

This file also contains seven fields:

(1) The first field in this screen is the antenna identification. Again as described earlier, this field is where you input any identifying nomenclature of the test antenna.

(2) The second field is the date. The default for this field is the computer system's date. If you do not want to change this value, hit "return"; otherwise type in the new date and then hit "return."

(3) The third field is the start position of the test antenna. Valid inputs for this field are  $-90^{\circ}$  to  $90^{\circ}$  inclusive. Any value not in this range generates an error and the computer beeps, pauses, and allows you to retype a response.

(4) The fourth field is the end position of the test antenna. The valid inputs for this field are the same as those for the start position; in addition, this field must be greater than the start position. If either condition is not met, an error occurs. The computer responds as described previously.

(5) The fifth field is the incremental position of the test antenna. This field determines when and where data points are taken during the test. The valid range for this field is the same as the start position and the end position. In addition, the incremental position must be less than the difference between the end position and the start position. If either condition is not met, an error occurs. Again, the computer responds as described previously.



(6) The sixth field is the power level. This field specifies the power level at which the signal generator is set during the test run. This field is numeric and the valid range of values is -90 to 10 inclusive. The unit of measure for this field is decibels referenced to 1 milliwatt.

(7) The last field is the frequency. This field specifies the frequency at which the test is conducted. This field is numeric and the unit of measure is gigahertz. Any positive number is a valid input to this field. A value equal to or less than zero generates an error, and the computer responds as described previously.

Now you are prompted to see if any changes are desired. If so, press "y" to begin. The process is exactly analogous to the one described in section 1.2.1.1, and therefore it is not repeated here. If no changes are desired, you are asked if you wish to save the file. If so, press "y"; otherwise press any other key to exit to the main menu and discard the information on the screen. If you press "y," you are asked if you wish to save the file on a floppy diskette. You may press "a" or "b" and hit "return" to specify drive A or drive B, respectively, as the destination drive. If no drive is desired, hit "return" and the file is not saved to the floppy. However, it is saved on the hard drive. Now, you are prompted to specify a file name (which must be not more than eight characters) for the setup file. After specifying a file name, hit "return." The program returns to the main menu unless there is a problem with the drive specified previously. If this is the case, the program jumps into the error-trapping routine. This routine helps identify the problem and allows you to correct the problem, and it gives you the option to continue by pressing "c" or to exit by pressing "e."

**1.2.1.3 Return to main menu:** The last selection under the create setup file menu is the return to main menu option. Selecting this option (by pressing "r" or using the mouse) exits you back to the main menu. You can later change one or more of the values in a file by choosing the edit file menu.

**1.2.2 Edit file.**—The second option of the main menu is called edit file. This menu option allows you to perform some useful DOS editing functions without exiting the program. The menu option has five selections: rename, delete, print, modify, and main menu. All of these selections operate on a previous created setup file. Each of these selections is discussed in turn. This option can be selected by using the mouse or pressing "e" on the keyboard.

**1.2.2.1 Rename file option:** The first selection is the rename file option. This option allows you to rename a previously stored file. It can be selected by using the mouse or pressing "r" on the keyboard. After this option has been selected, the program exits to the file management menu in the rename file mode. The following fields define this option:

(1) The first field name is the old file name. Here you specify the name of the file to be changed. Note that this file must already exist or an error occurs.

(2) The next field is the scan type. Here type either "f" or "p" to specify frequency sweep or pattern sweep, respectively. Any other response generates an error. If an error does occur, you are then allowed to retype the response after a brief pause.

(3) The last field name is the new file name. Here you specify the new or desired file name of the file being changed. This new file name must be a valid file name and must not already exist; otherwise an error occurs.

An error that is generated by the old file name or new file name fields is handled by an error-trapping routine that allows you to view the files which exist on the hard drive. Then it lets you specify a different entry to the old file name or new file name field, depending on which field generated the error. Furthermore, it allows you to exit the option without retrying to rename the file. After valid file names have been specified, the program renames the files and exits to the main menu.

**1.2.2.2 Delete file option:** The second selection under the edit file menu is the delete file option. This option allows a file stored on the hard drive or the floppy disk to be deleted from the current directory. It can be chosen by using the mouse or by pressing "d" on the keyboard. After this option has been chosen, the program exits to the file management menu in the delete file mode. The following fields define this menu option:

(1) The first field name in this menu is "delete file name." Here you specify the name of the file to be deleted.

(2) Next, you are asked if you are certain about deleting this file. If the file cannot be found, an error occurs. You are then given the opportunity to reenter a new file name. After a valid file name has been specified, the program deletes the file from the hard drive or the floppy disk. Now press any key to exit to the main menu.

**1.2.2.3 Print file option:** The third selection under the edit file menu is the print file option. This option allows you to print the contents of any previously stored setup file on the printer connected to port lpt1. Select this option by using the mouse or by pressing "p" on the keyboard. Once this option has been chosen, the program exits to the file management menu in the print file mode. This menu option contains only two field entries. The first field is entitled "file to print" and the second field is the scan type. Type the name of the file to be printed in the first field, and type either "f" or "p" for the scan type. If the file name specified cannot be found, an error occurs and is handled as described previously. Peripheral timeouts also cause an error. The computer suggests what might be the problem and pauses while you attempt to correct it. You are then given the option to continue or to exit to the main menu. If you choose to continue, the file is printed to the printer and the program exits to the main menu. On the other hand, if you choose to exit, the program immediately returns to the main menu.

**1.2.2.4 Modify file option:** The fourth selection under the edit file menu is the modify file option. This option allows you to modify the contents of any existing file stored on the hard drive. It can be chosen by using the mouse or by pressing "m" on the keyboard. Choosing this option exits the program to the file management menu in the modify file mode. In this screen you are prompted to specify the name of the file to be modified and its scan type. After these two field entries have been specified, the program searches the hard drive under the current directory for the desired file. If the file cannot be found, an error is generated and the error-trapping routine takes command of the program execution. This error-trapping routine is very similar to those described previously. It lists all valid file names stored on the hard drive in the current directory and provides an opportunity for you to reenter the file name and the scan type. Once a valid file name has been given, the contents of that file are displayed on the screen. Next you are asked if you want to change any of the field entries. If you choose to do so, press "y" to begin the process. Press any other key to exit to the main menu. If you press "y," you are asked to type in the number corresponding to the field to be changed. After the number has been specified, the cursor moves under the first character of the currently stored response to the specified field. Now you may type in a new entry and hit return. Then you are queried if you

want to change any more values. If so, type "y" and repeat the preceding steps; otherwise press any other key. After you have modified the contents of the file, you are asked if you want to save the changes. If so, type "y"; otherwise press any other key to exit to the main menu. If you choose to save the changes, the entries displayed on the screen at that time are stored in the file under the same name as previously specified. Once the new values have been stored, you are asked if you want to run the file. If so, press "y" and the program exits to DOS; type "run" to begin program execution. Otherwise press any other key to exit to the main menu.

**1.2.2.5 Main menu option:** The last selection under the edit file menu is the main menu option. This option returns program control to the main menu. It can be chosen by using the mouse or by pressing "a" on the keyboard.

**1.2.3 Run test.**—The third option of the main menu is called the run test. This option allows you to run a test from a previously created setup file. It can be chosen by using the mouse or by pressing "r" on the keyboard. This menu option has three selections: frequency sweep, pattern, and main menu. If either frequency sweep or pattern is chosen, the program exits to "run test" in the frequency sweep mode or the pattern mode, respectively. Next you are asked to specify a file name. If the file name cannot be found, the computer displays an error message, and after a brief pause you are allowed to type in a new file name. The program continues in this loop until a valid file name has been specified—press the "control" and "c" keys simultaneously to exit and restart the program. When a valid file name has been specified, the program exits to the DOS operating system with a message displayed on the screen to type "run" at the DOS prompt. The file "run.bat" begins program execution. The computer transfers control to the HP Basic operating system. In this environment you are prompted at various points in program execution to hit "continue" (F2) to resume testing. After the test is completed, you are prompted to display and save the data taken, and control is returned to the DOS operating system. However, at any time during program execution, you can press the abort test key to stop the test. Caution—this will destroy all data taken up to that time. Also if a limit switch is activated during program execution, press the limit switch key to handle the problem. If the program is terminated prematurely, press the shift and F9 keys simultaneously to return control to DOS. Once at the DOS prompt, type "return" to return to the FAMP program.

If the main menu is chosen, either by using the mouse or by pressing "m," the program exits to the main menu. Note that after a test run has been completed, the data from this test run are stored on the hard drive and can be inspected by choosing the view data menu.

**1.2.4 View data.**—The fourth option of the main menu is called view data. This option allows you to view the results from a test run. It can be chosen by using the mouse or by pressing "v" on the keyboard. A popout menu then appears. There are four types of plots: (1) amplitude versus frequency, (2) amplitude versus angle, (3) phase versus frequency, and (4) phase versus angle. Each selection is discussed here in detail.

**1.2.4.1 Amplitude-versus-frequency plot:** The first selection under the view data is the amplitude-versus-frequency plot option. This option is available only to those setup files that were created in the frequency sweep menu. It can be chosen by using the mouse or by pressing "1" on the keyboard. Once this plot has been selected, you are prompted to specify the file name from which the data will be read. This file name is the same name as the setup file used to control the test run. At this point it is possible to generate one of two types of error: (1) the setup file cannot be found, or (2) the data file corresponding to the specified setup file cannot be

found. In either type an error-trapping routine is activated, and you are given the option to view the valid file names stored on the hard drive under the current directory. If the first error mentioned occurs, check if the file was ever created or if the file is located in some directory other than the current directory. If the second error occurs, double check if the test run was made or if the data file is located in a directory other than the current directory. In either of the two types where the file is located in a directory other than the current one, copy the file into the current directory. Once a valid file name has been specified, the computer graphs the data on the screen and asks if you desire a hard copy. Note that the hard copy and the screen output are identical; this type of plot is illustrated in figure 4. If you want a hard copy, press "y" to start the plotting routine. Press any other key to exit to the main menu. Once the plot is finished, the program exits to the main menu.

**1.2.4.2 Amplitude-versus-angle plot:** The second selection under the view data menu is the amplitude-versus-angle plot option. This option is available only to those setup files that were created in the pattern sweep menu. It can be chosen by using the mouse or by pressing "2" on the keyboard. Once this option has been selected, you are asked to specify a file name. Here again the file name specified is the same as the setup file used to perform the test. The two types of error mentioned previously can also occur here. Follow the instructions outlined in the previous section to correct any problems. Again after a valid file name has been given, the program plots data and asks if you want a hard copy. If so, press "y." After the plot is finished, the program exits to the main menu. This type of plot is illustrated in figure 5.

**1.2.4.3 Phase-versus-frequency plot:** The third selection under the view data menu is the phase-versus-frequency plot option. This option is available to those setup files that were created in the frequency sweep option. It can be chosen by using the mouse or by pressing "3" on the keyboard. Just as in the preceding two cases, you are prompted to specify a file name after this menu option has been picked. The suggestions given for those cases are also applicable here. Again after a valid file name has been specified, the computer plots data to the screen and asks if you want a hard copy. If so, press "y"; otherwise press any other key to exit to the main menu. When the plot is complete, the program exits to the main menu. This type of plot is illustrated in figure 6.

**1.2.4.4 Phase-versus-angle plot:** The last selection available in the view data menu is the phase-versus-angle plot option. This option is available to those setup files that were created in the pattern sweep option. It can be chosen by using the mouse or by pressing "4" on the keyboard. This option is very similar to the three already described. Review previous sections for greater detail. Once this option has been selected, you must specify a file name. After the file name has been specified, the computer plots the data and asks if you want a hard copy. If so, the program exits to the main menu immediately after completing the plot. This type of plot is illustrated in figure 7.

**1.2.5 Quit.**—The last option available in the main menu is called quit. As suggested by its name, this option exits from the program. It can be chosen by using the mouse or by pressing "q" on the keyboard.

This concludes the discussion of the software aspects of this document. All sections to follow discuss the operation of the controller system.

## 2.0 THEORY OF OPERATION

All the circuits contained in the controller system are described here in full detail. The controller system is the interface through which all motors to the pedestal and the cart are speed and position controlled. The schematic circuit diagrams of the system are shown in figure 8; the overall system integration is shown in figure 9. The design of this system entailed several problems. First, an interface through which the computer could talk to all the controlling hardware was needed. Second, once this interface was available, a circuit was needed that would convert the digital outputs to analog outputs of the proper voltage levels for running the motors. Third, the position of the pedestal was needed. Fourth, a circuit was needed that would distribute the analog voltages to the three motors. Last, a controller circuit was needed that would drive the rail on which the cart holding the source antenna and the other microwave equipment rests. These problems were tackled and solved individually. The solution of each problem is discussed in its own section. There are five major sections: the general-purpose input/output (GPIO) interface circuitry, the speed-and-direction-controlling circuitry, the position-recording circuitry, the axis-selecting circuitry, and the cart-positioning circuitry.

### 2.1 GPIO Interface Circuitry

The GPIO interface circuitry provides an interface between the computer and the external hardware. All communications from the computer to the antenna control and measurement system (ACMS) are accomplished through this interface. The principle upon which this circuitry operates is relatively simple. The computer outputs data in a binary format, and the ACMS accepts data in a binary format. However, the computer does not have the same electrical specification as the inputs to the ACMS; therefore it is necessary to use pullup resistors to interface the two. The output of these pullup resistors is the input to latches. These latches store the voltage level of the pullup resistor until the computer outputs a signal that allows new values to be stored. This computer signal is the peripheral control line (pctl), which is pin 19 on the GPIO connector. This line also requires pullup resistors. The peripheral control line controls the latches in the following manner: The peripheral control line is connected to the clear inputs of the latches. When the clear input of a latch is a low signal, further updates to the output of the latch are disabled. When the clear input is a high signal, the output of the latch is continuously updated. When the peripheral control line is pulsed low during data transmission to the ACMS, the output of the latch changes to reflect the new data. This topology prevents spurious computer data from being sent to other parts of the ACMS and resulting in uncontrolled behavior. The outputs of the latches are connected to the inputs of the speed-and-direction-controlling circuitry.

### 2.2 Speed-and-Direction-Controlling Circuitry

The speed-and-direction-controlling circuitry controls the speed and direction of the motor according to the reference input—through the GPIO circuitry—from the computer. This circuit consists of four main parts: the Analog Devices AD DAC85 12-bit digital-to-analog (D/A) converter integrated circuit, the magnitude circuit, the phase circuit, and the Sprague UDN-2954 full-bridge pulse-width-modulated (PWM) motor driver. All these parts control the speed and direction of the motor. First, the latched outputs of the GPIO circuitry are connected to the input of the D/A converter. The D/A converter converts the digital output of the computer to an analog voltage that is used to indirectly control the speed and direction of the motor. The output of the D/A converter is a voltage between 10 V and -10 V, depending on the input to the circuit. For example, if the computer outputs the decimal number 4095 whose binary

representation is 1 1 1 1 1 1 1 1 1 1, this series of ones is the input to the D/A converter, which then outputs a voltage of  $-10$  V. On the other hand, if the computer outputs the decimal number 0 whose binary representation is 0 0 0 0 0 0 0 0 0 0, the output of the D/A converter will be a voltage of  $10$  V. By transmitting numbers from 0 to 4095 from the computer, the output voltage of the D/A converter can be precisely controlled within a few hundredths of a volt. This voltage is the input to the magnitude circuit.

The magnitude circuit performs full-wave rectification. If the input to the circuit is  $-10$  V, the output is  $10$  V. If the input is  $10$  V, the output is also  $10$  V. This circuit operates on the following principle: When the input to the magnitude circuit is a positive voltage, diode D1 is conducting and diode D2 is off. Under these conditions the two operational amplifiers act like unity-gain inverting amplifiers. Therefore the output equals the input—the desired result. On the other hand, if the input to this circuit is negative, diode D2 conducts and diode D1 is off. Under these conditions the operational amplifier in the first stage acts like an unity-gain inverting amplifier, and that in the second stage acts like a unity-gain voltage follower. Therefore the output equals the magnitude of the input, which is positive. The output of this circuit is one of the two signals used to control the operation of the motor driver.

The other signal used to control the motor driver is the output of the phase circuit. This circuit outputs either a high (binary 1) or a low (binary 0) signal that is used by the motor driver chip to determine the direction in which the motor turns. This circuit consists only of a simple inverter. This inverter changes the motor direction when the voltage out of the D/A converter is changed from positive to negative or vice versa. The input to this inverter is the most significant bit of the input to the D/A converter. This bit is used because its value only changes when the voltage changes sign. Both outputs of these two circuits are used to control the behavior of the motor driver chip.

The motor driver chip controls both the speed and direction of the motor depending on the voltage levels connected to its voltage reference input (pin 2) and phase input (pin 7). The motor driver chip accepts control signals from the computer and outputs a variable current that completely controls the behavior of the motor. The motor driver operates as follows: When the input to pin 2 is between  $0$  V and  $2.4$  V, the motor will be dynamically braked. That is, the four transistors used to drive the motor will have equal currents flowing through the motor's armature winding in opposite directions. (Refer to the Sprague IC Data Book, pp. 4–70 to 4–73.) However, if the voltage is greater than  $2.4$  V, only two of the four transistors will conduct and drive the motor's armature winding. The current flowing through the armature winding will be directly proportional to the voltage applied to the reference voltage input, which is greater than the threshold of  $2.4$  V. In this way the motor speed is under computer control. The motor direction is controlled through its phase input (pin 7). When the phase input is a high signal—the output of the D/A converter is positively signed—the pedestal rotates counterclockwise in the azimuth. Conversely, if the phase input is a low signal—the output of the D/A converter is negatively signed—the pedestal rotates clockwise in the azimuth. In this manner, the motor direction is computer controlled.

### 2.3 Position-Recording Circuitry

The position-recording circuitry provides the pedestal position to the computer. The Scientific Atlanta digital synchronous display model 1842 (located in the far-field laboratory) displays the pedestal's position continuously and accurately. The synchronous display provides a binary-coded decimal (BCD) data output for computer control. With this output the pedestal

position can be read. The BCD-formatted data are converted to decimal format by software programming.

At this point the position and speed of one motor can be controlled. It is desired to provide a circuit that expands this control to two additional motors.

## **2.4 Axis-Selecting Circuitry**

The axis-selecting circuitry distributes the control of the computer to two additional motors. Also included in this circuit are some safety features that enhance the design.

Because the control signals that are necessary to control a motor are already available, adding two motor driver chips would provide the proper control voltages for the other two motors. Switching between motors is accomplished through a multiplexed switching network. The circuit operates in the following manner: First, the computer selects an axis through two unused output data lines (pins 4 and 5). These outgoing lines from the computer have been connected to the select input pins of a 2-to-4-line multiplexer and a 4-to-1-line demultiplexer in the motor control unit and the select unit. Three of the four outputs of the multiplexer are connected to the output-enabling pins of the motor driver chips. This output enabling pin enables motion when its input is a low signal and disables motion when its input is a high signal. The output lines of the multiplexer are normally high signal until one of them has been selected. Once a line has been selected, the output line corresponding to the selection will be driven to a low signal. The other lines remain high signals. Therefore only one motor is enabled at a time. The synchronizer recording the position of the axis being controlled is selected through the synchronizer select unit, which consists of nine 4-to-1-line multiplexers (see fig. 8 concluded). Through this scheme the computer can enable any motor, control its speed and direction, and measure the current position of the pedestal.

The design contains the following safety features: First, all motors are disabled when the computer resets and powers up the motor controller system; the motors remain disabled until the computer selects one of them. Second, limit switches are installed at various safety points; the switches are positioned so that the pedestal does not wrap around and damage the cable and other equipment. When the pedestal hits a limit switch of that axis, the limit switch generates a high signal that is connected to one of the inputs of the demultiplexer. The computer can sense when the pedestal stops moving and will take the appropriate steps to correct this situation—return the cart to the boresight position—and then stop the test so that the source of the problem can be found and resolved.

## **2.5 Cart-Position-Controlling Circuitry**

The cart-position-controlling circuitry controls the motion of cart on which the signal generator and the local oscillator rest. The circuit is controlled by the computer through the IEEE 488 bus at address 04 and is shown in figure 10. The main components of the circuit are an 8751 microcontroller, a D/A converter, and an analog-to-digital (A/D) converter. The circuit works on the following principle: The pulse-width-modulated amplifier board of the Electro-Craft Corporation's PROPOS system is used to drive the cart along the rail. The output of the D/A converter is connected to the velocity control signal (VCS) input of the amplifier board. (Refer to PWM Amplifier Instruction Manual for SA-9000 Series.) The VCS input accepts a voltage between 10 V and -10 V and uses this voltage to control the rotational direction and speed of the shaft.

The D/A converter is programmed by the 8751 microcontroller during operation; the microcontroller receives the test instruction through the IEEE 488 bus. The test instruction is a character string and has the following format: MOV;dest. For example,

OUTPUT 704 USING "+,K";"MOV;563"

is a valid test instruction that can be programmed in HP Basic. Please note that the image string must be used when sending data to the system. MOV is the key word which tells the microcontroller that the next groups of characters following the semicolon should be interpreted as a decimal number. The first operand "**dest**" is the location where the cart is to be moved. The number sent is the A/D converter reading when a desired position has been reached. The conversion between the position in millimeters  $\beta$  to the A/D number  $\gamma$  can be computed with the following equation:

$$\gamma = \frac{104.4 \beta}{725}$$

The desired far-field position can be either calculated by using the  $2D^2/\lambda$  formula (where D is the antenna diameter and  $\lambda$  is the wavelength) or looked up in the conversion table found in the book labeled "Far-Field Antenna Facility Information."

Once the microcontroller receives a valid test instruction, the cart moves toward the destination position. During this time the A/D converter samples the output of the Celesco SE-2000 display. The Celesco SE-2000 display outputs an analog voltage between 0 and 10 V that is directly proportional to the currently displayed position. By continuously polling the A/D converter, the microcontroller can monitor the cart's position as it travels along the rail until the destination position has been reached. The microcontroller stops the cart once it detects that the current A/D reading corresponds to the desired destination.

If for some reason one of the operands or the operating code (opcode) is incorrect, the microcontroller will output an error byte that can be read through the IEEE 488 bus. The error bytes and their meanings are listed here:

- (1) 0: This error code means an invalid operating code. The microcontroller did not receive the word "MOV" as the first three characters over the bus.
- (2) 1: This error code means an invalid destination. Either the destination is not separated from the operating code by a semicolon, or the destination is not between 300 and 965, which are the programmed limits for safety considerations.
- (3) 2: This error code means an invalid source. The comments for error code 1 are applicable here as well. The operator should check the connection between the output of the Celesco SE-2000 display and the input of the A/D converter.

## CONCLUDING REMARKS

This document has described the operation of the Far-Field Antenna Measurement Program (FAMP) and the theory of operation for the controller system. The description entails step-by-



step instructions in the use of all the features of FAMP as well as a comprehensive discussion of the theory of operation for each controller component.

## **ACKNOWLEDGMENTS**

I would like to acknowledge everyone who helped in the development of this manual. First, I would like to thank technicians Emye Bevenage and Tom Marino for the professional job they each did in building the components for the automated system. Furthermore, I would like to thank Emye Bevenage for her help in developing some of the schematics shown in this document. Also, I would like to acknowledge both Richard Kunath and Robert Zakrajsek for all their technical advice and mentorship. I would like to further acknowledge Robert Zakrajsek for reviewing this report.

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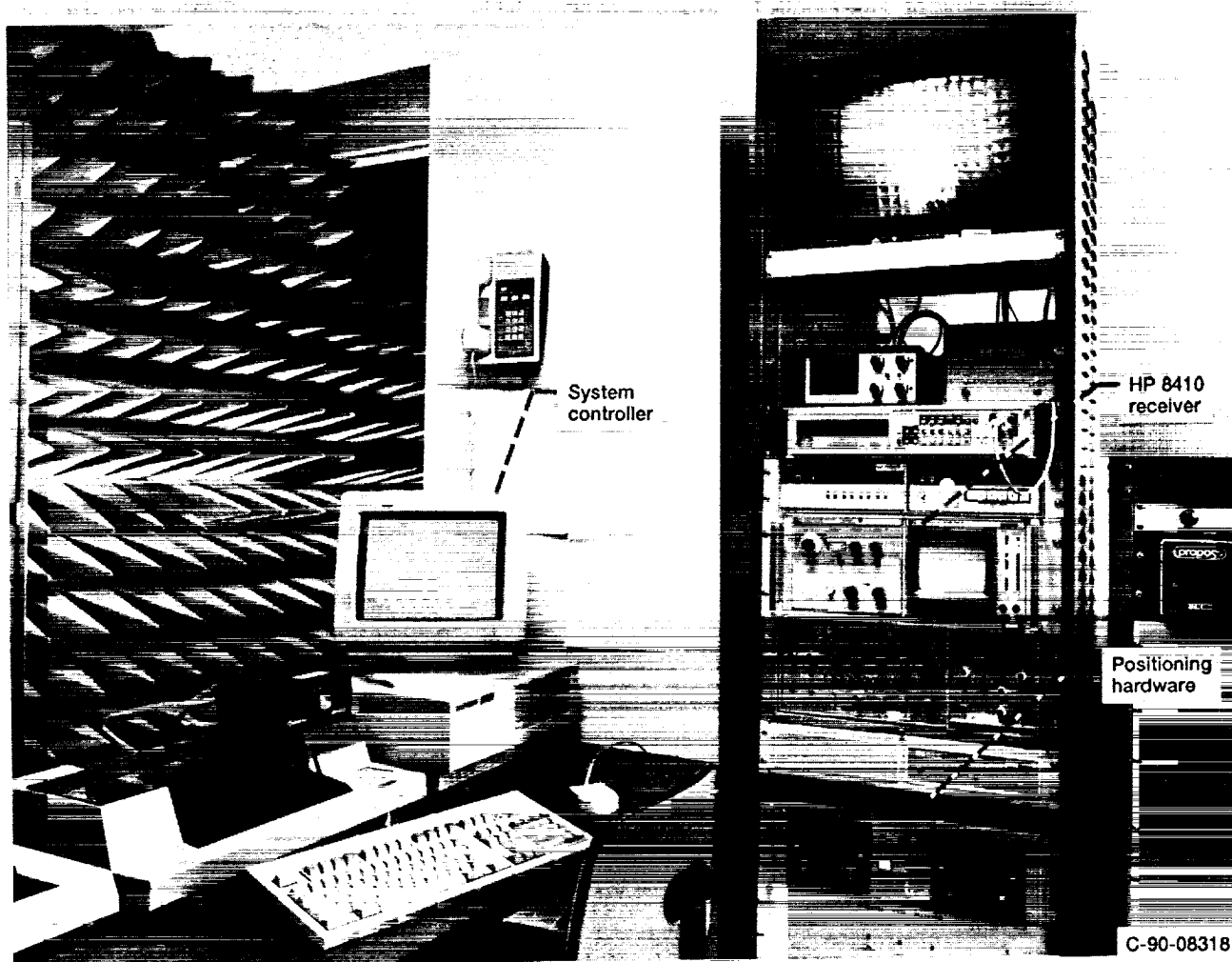


Figure 1.—Control room.

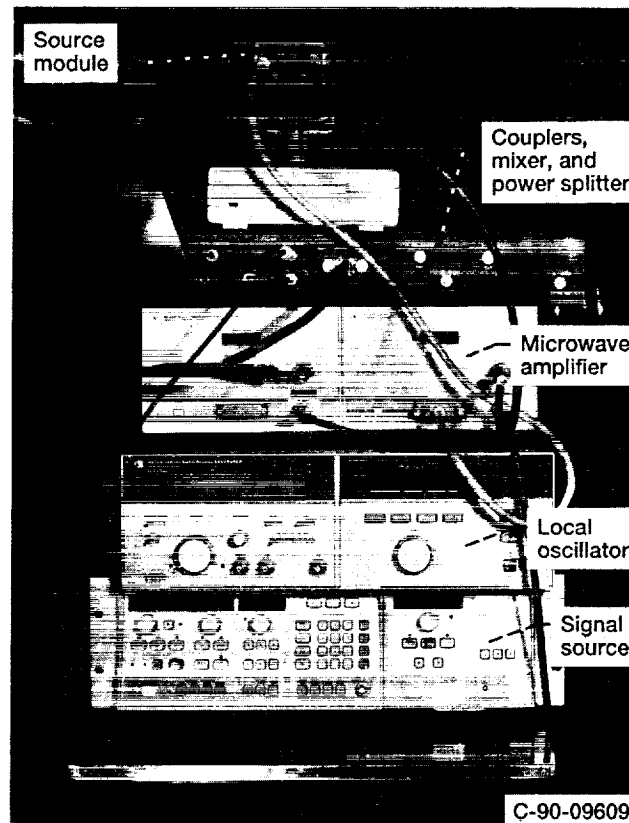


Figure 2.—Microwave hardware.

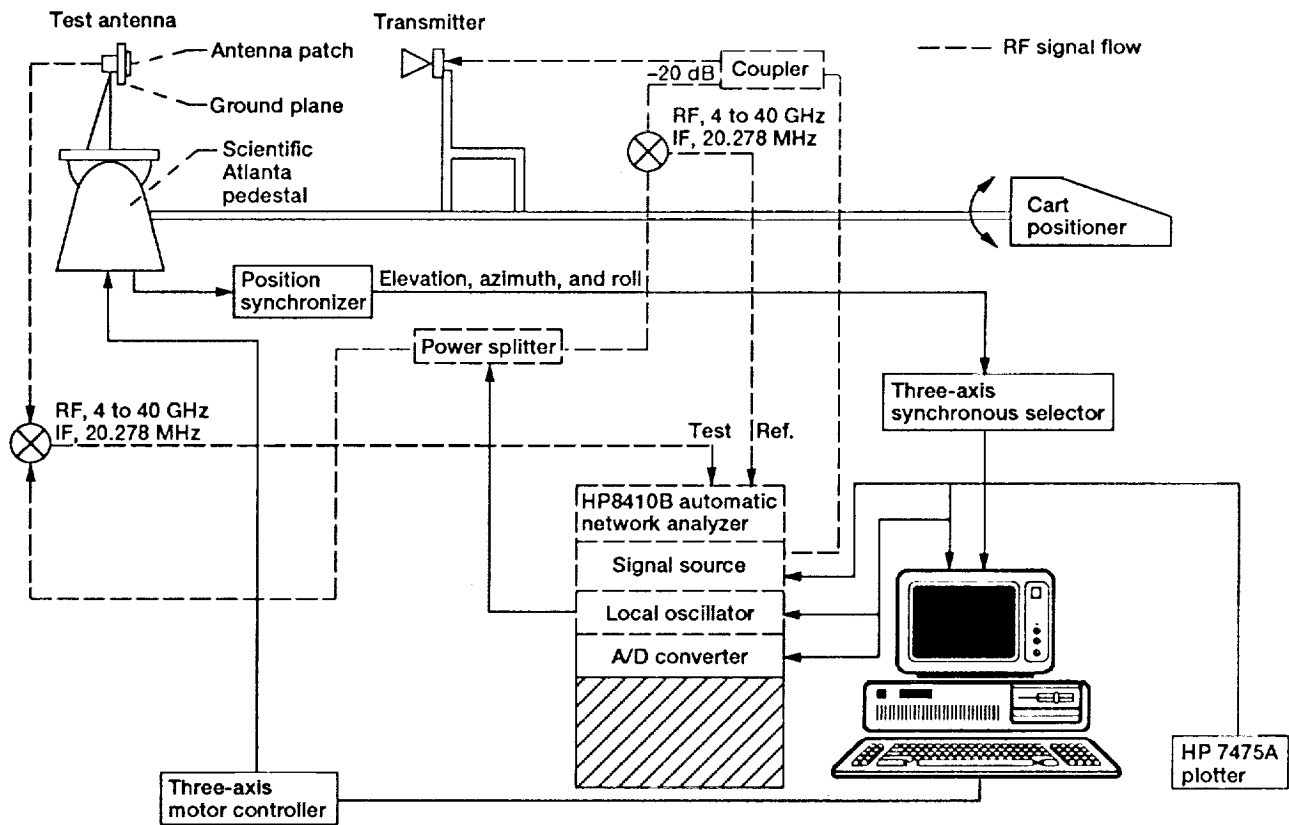


Figure 3.—Functional block diagram showing RF signal flow.

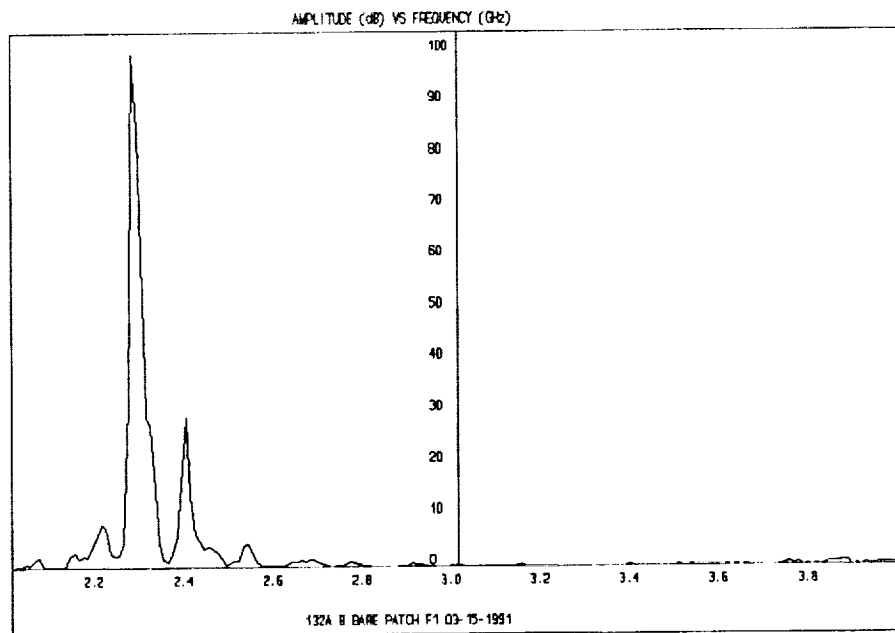


Figure 4.—Amplitude-versus-frequency plot.

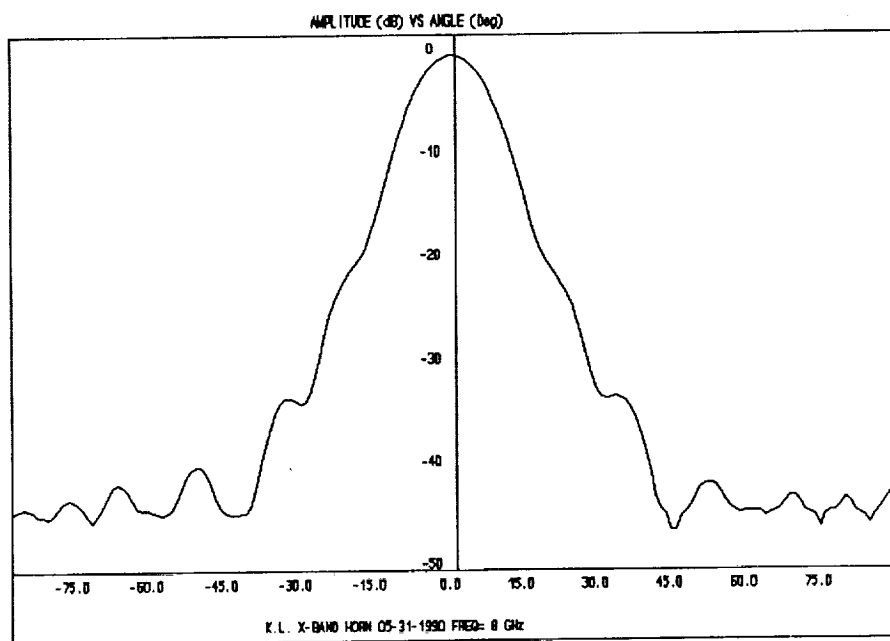


Figure 5.—Amplitude-versus-angle plot.

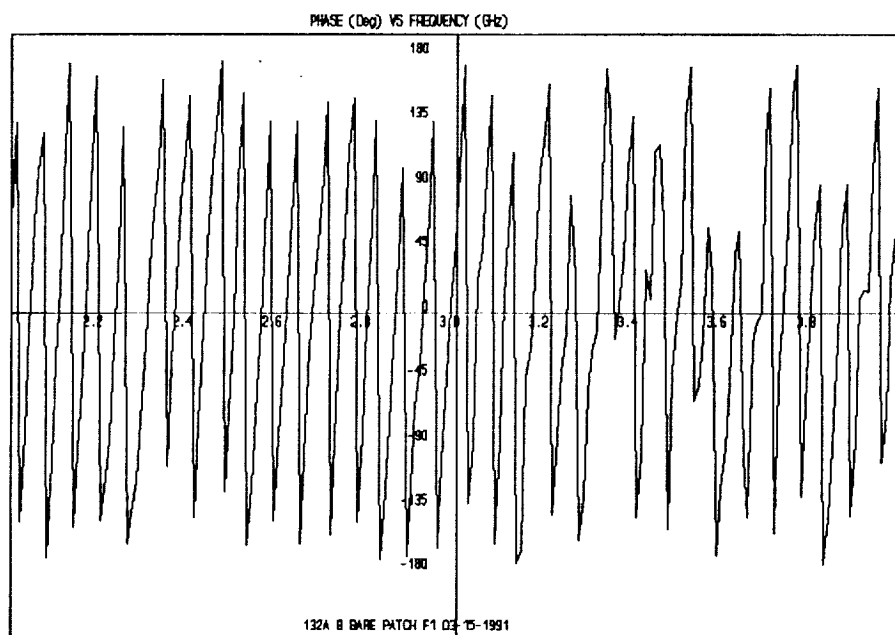


Figure 6.—Phase-versus-frequency plot.

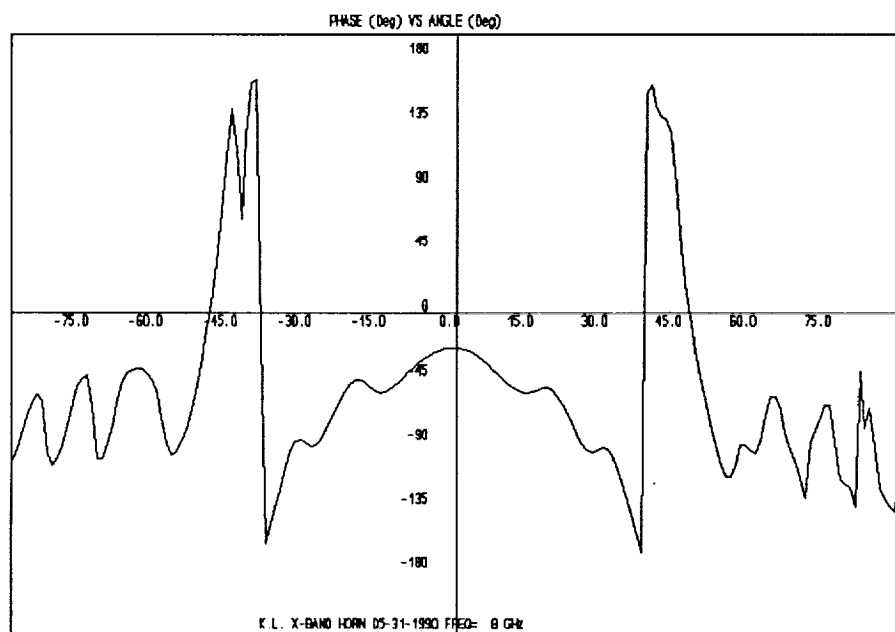
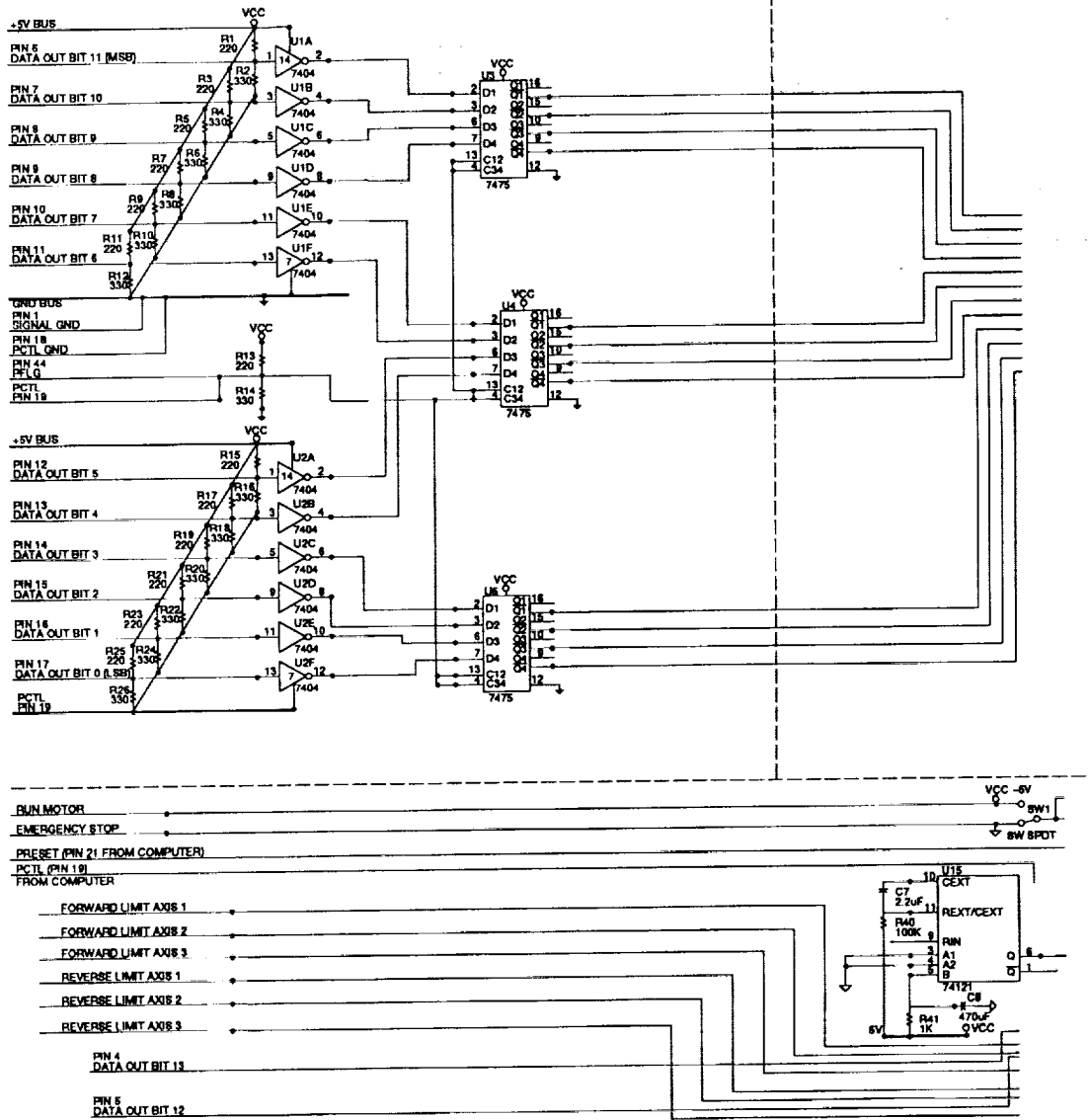


Figure 7.—Phase-versus-angle plot.

# GPIO Interface circuit



Axis selection circuits

Figure 8.—Schematic

## Speed and detection control circuit

## Motor drivers

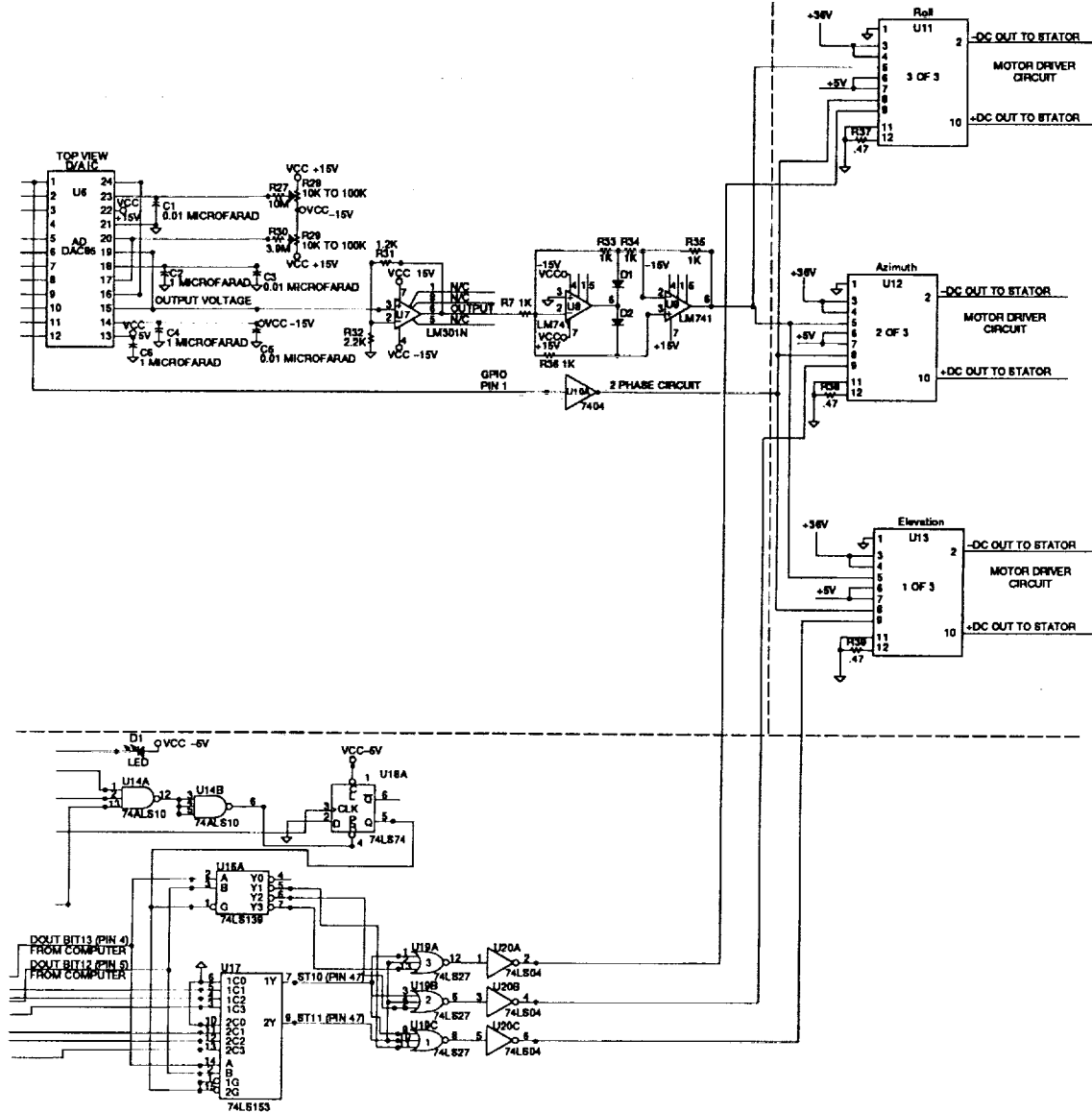


diagram of system.

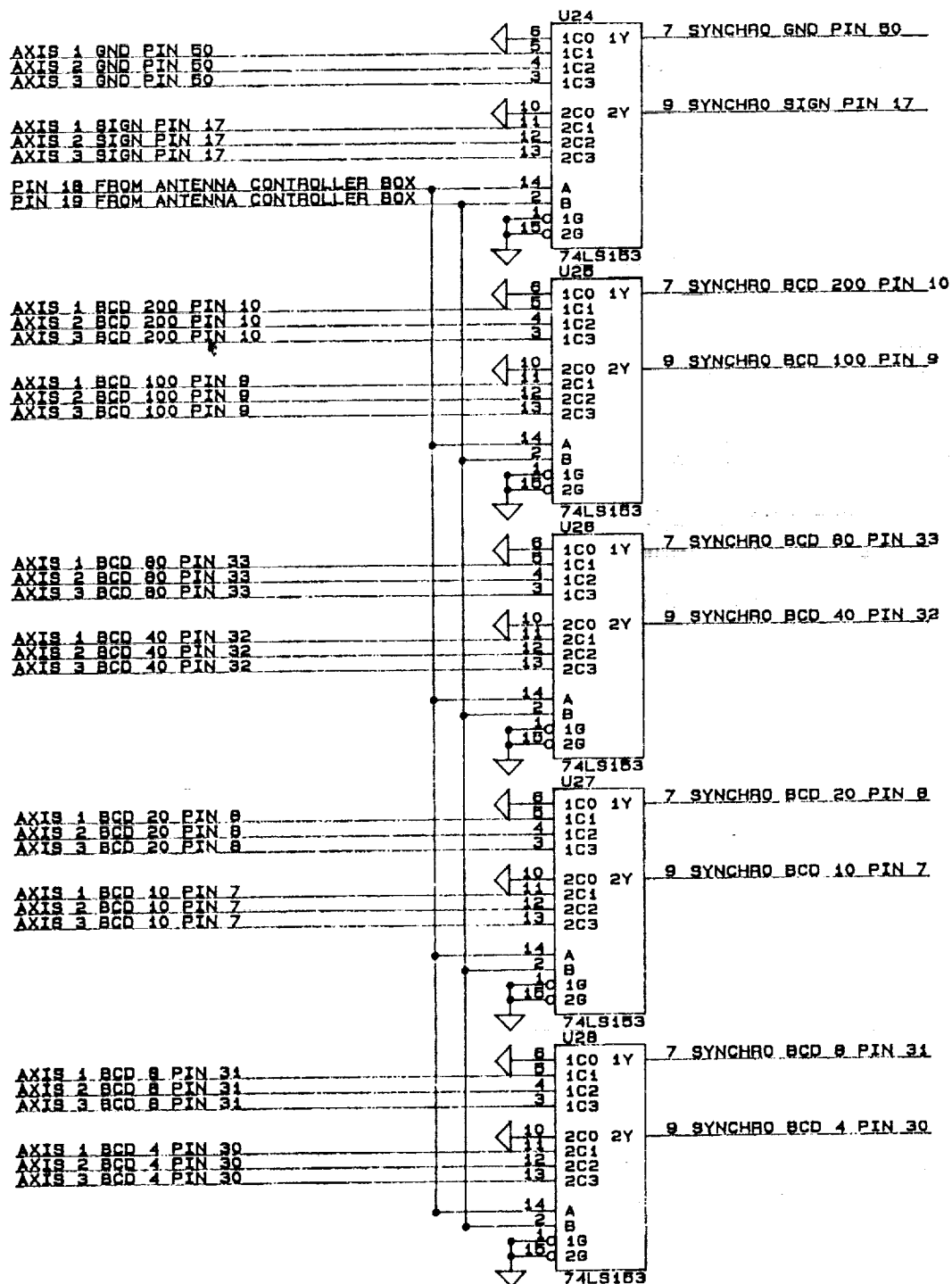


Figure 8.—Continued.



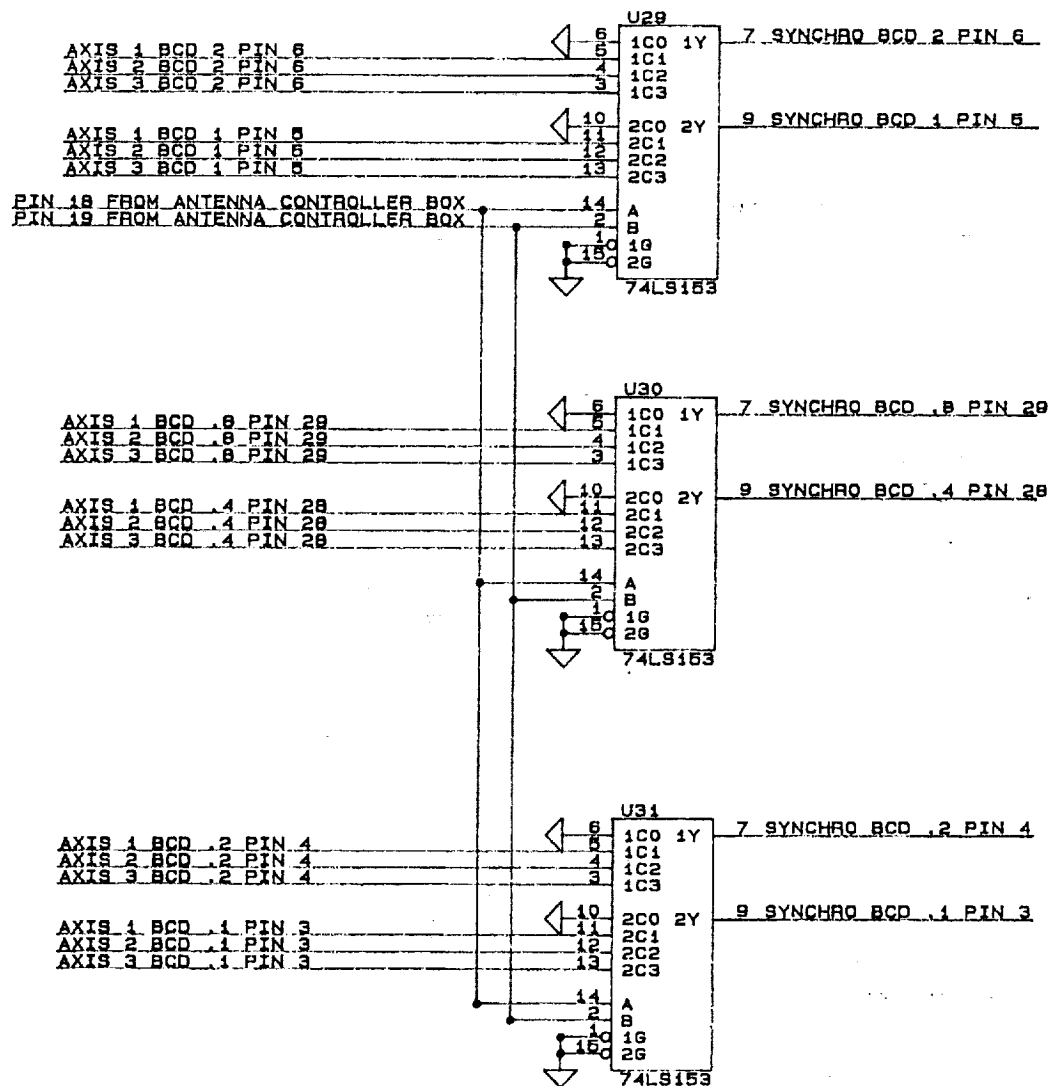


Figure 8.—Concluded.

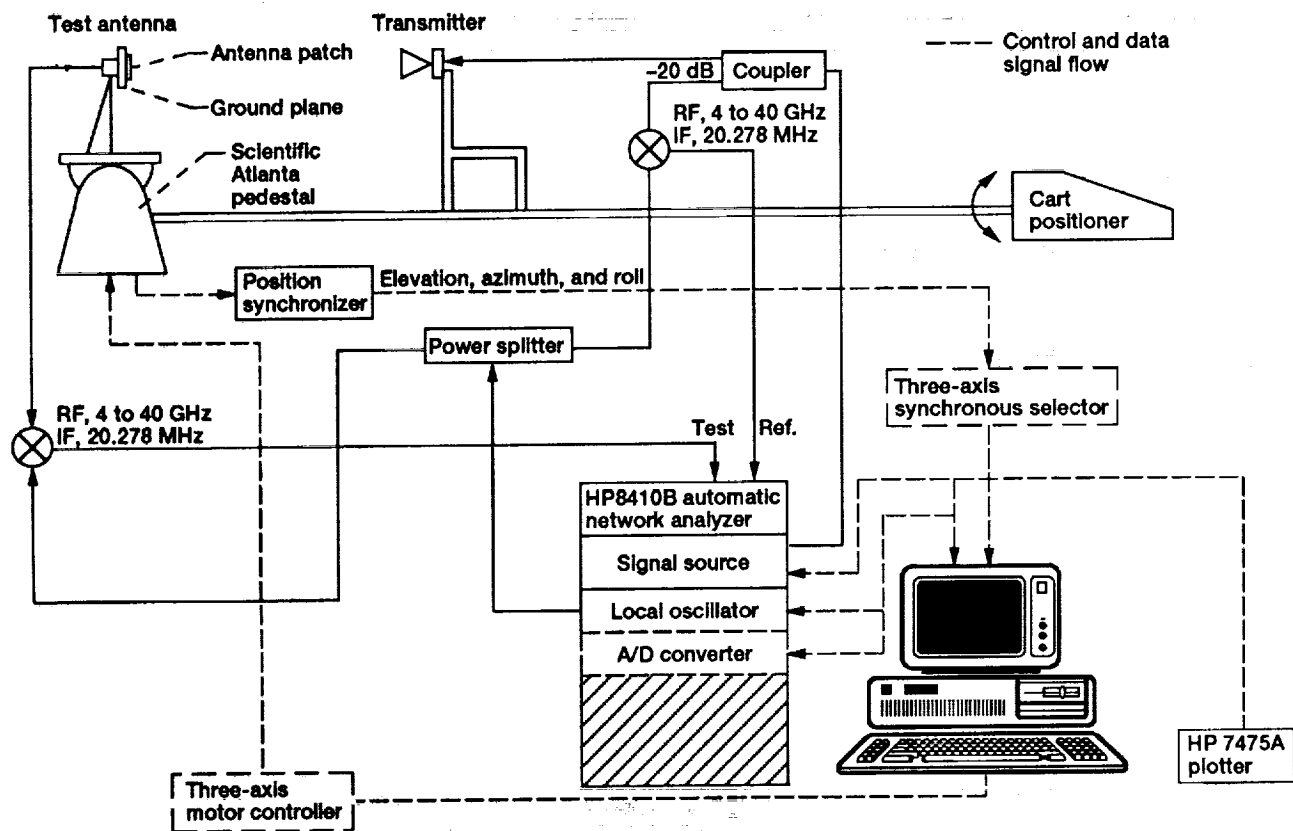
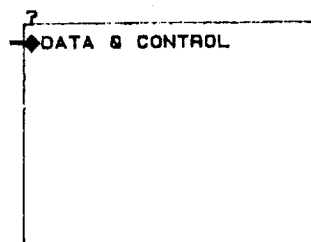
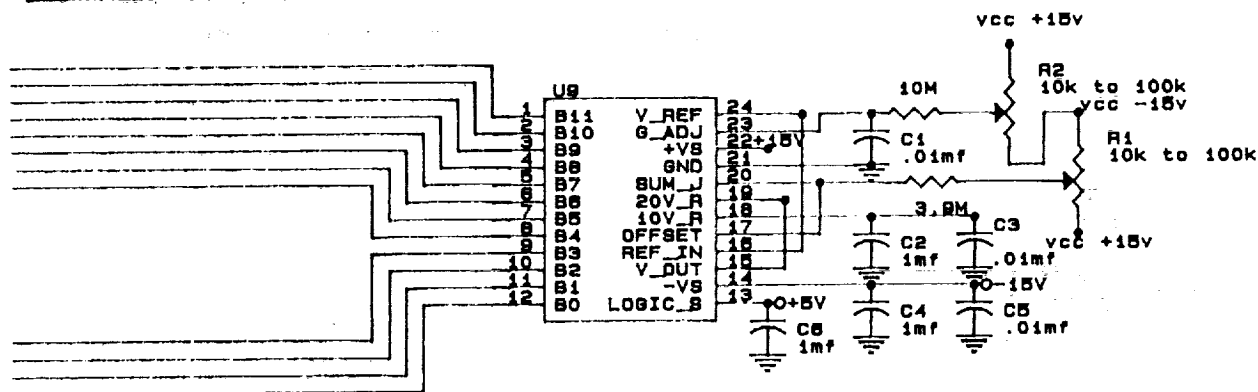
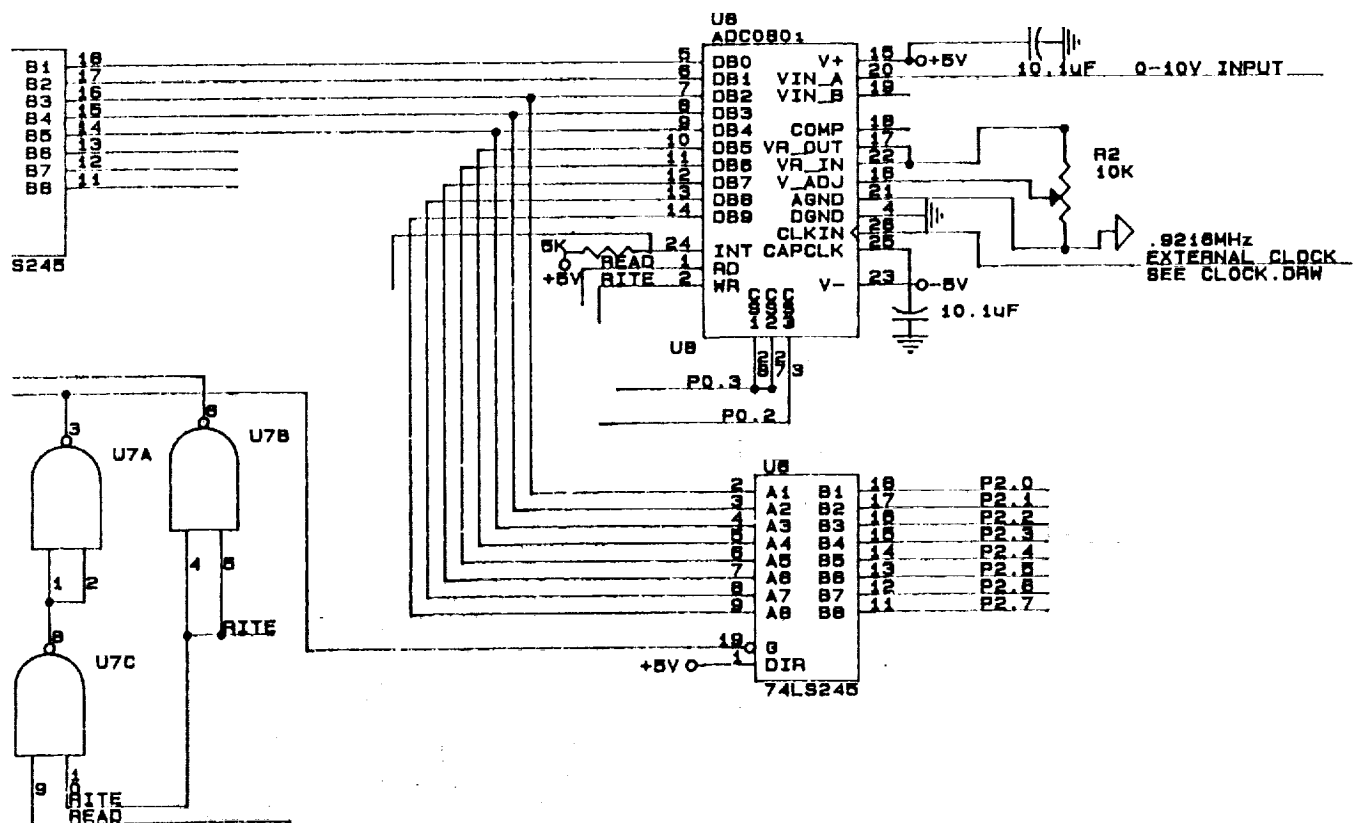


Figure 9.—Functional block diagram showing control and data signal flow.





control circuitry.



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